ENERGETICS

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Published by the Ontario Ministry of Agriculture and Food · Agricultural Energy Centre · 801 Bay Street · Toronto · M7A 2B2 · (416) 965-9519

AGDEX 261

717

87-4614

AIR-TO-AIR HEAT EXCHANGER FOR A MUSHROOM FARM

FINAL REPORT

Partial funding for this project was supplied by Ontario Ministry of Energy.

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MAY 1987

ABSTRACT

A site built, cross-flow, air-to-air heat exchanger was built and tested in a commercial mushroom plant. The initial $7,400 cost of the heat exchanger can be recovered, within 2 years from the energy recovered.

AIR-TO-AIR HEAT EXCHANGER FOR A MUSHROOM FARM

BY

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ONTARIO MINISTRY OF AGRICULTURE AND FOOD

INTRODUCTION

Proper ventilation and temperature control is critical to provide the desired environment for continuous production in a commercial mushroom plant. During most of the year the plant exhaust air temperature is in the range of 18°C. Heat which is contained in this exhaust air, can be easily recovered with a heat exchanger. This heat can be used to provide a part of the heating requirements of the mushroom plant.

A large cross-flow, plate type heat exchanger was constructed and tested at Elgin Mushrooms Ltd. This mushroom production facility was built in the late seventies and has an annual production of roughly 364,000 kg of mushrooms.

OBJECTIVE

To determine the payback period for a farm-built heat exchanger used to recapture heat from the exhaust air from a mushroom plant.

NOTE: The mention of manufacturers' trade names is for the purposes of specific equipment description and does not indicate an endorsement of that equipment of discrimination of similar equipment by the author or Ontario Ministry of Agriculture and Food.

SYSTEM

The main supply air and exhaust air plenums at this location are situated adjacent to one another which meant that a heat exchanger could be installed with minor duct modification. The heat exchanger was built on site, utilizing a plastic matrix core and a cross-flow design with the exhaust air and intake air travelling at 90° to each other. The actual heat exchanger core consists of coroplast sheets. These coroplast sheets are made of extruded polypropylene, corrugated to form twin walled sheets with many narrow internal channels. Each coroplast sheet has an overall thickness of 5 mm.

The core of the heat exchanger is comprised of coroplast sheets 1800 mm long by 2100 mm wide laid horizontally. Between each coroplast sheet 25 mm wide strips of coroplast are used as spacers. The strips run perpendicular to the internal channels and are spaced every 250 mm. A thin film of silicone sealant is used to seal between the sheets and spacer strips. Coroplast sheets, 122 in total, along with spacers between each, are stacked up to form the core.

The overall dimensions of the coroplast core are approximately 1200 mm high by 1800 mm wide by 2100 mm long. Threaded rods were also installed through the coroplast core to mechanically fasten it together. Figure 2 illustrates how these sheets were stacked together.

This plastic core was supported inside a sheet metal housing and sloped both along its length and width. This provides for drainage of condensate out of the heat exchanger core.

The existing supply air and exhaust air fans were used to move air through the heat exchanger. Outside air is drawn into the intake plenum, through a roll filter and through the channels of the coroplast sheets. From here it then passes through the bag filters, and the fan, then supplied to the plant. The exhaust air from the plant is blown by a separate fan through the heat exchanger passing between spaces between the coroplast sheets, then to the outside. Figure 1 illustrates graphically how air moves through the heat exchanger.

A preheat coil was installed in the fresh air intake plenum. The main purpose of this preheat coil is to warm the incoming air if hoar frost starts to build up on the roll filters. This slight warming of the air would be enough to melt this frost.

An exhaust bypass damper was installed in the exhaust air plenum. This damper was to allow complete bypass of the heat exchanger for summer operation. However, since the heat exchanger provides some supply air cooling, the damper has not yet been activated.

MONITORING

Temperature monitoring was conducted in 1986. Temperature readings were taken approximately once weekly. Relative humidity readings were obtained from London office of Environment Canada.

To demonstrate the heat exchanger's performance, a digital thermometer and a rotary switch were installed, with thermocouple wires leading to various locations, where the following temperatures were monitored.

To - outside ambient air temperature measured at the fresh air inlet

Ti - inlet air temperature measured in the plenum after the heat exchanger

Tp - plant exhaust air temperature measured in the exhaust plenum before the heat exchanger

Te - exhaust air temperature measured after the heat exchanger

Thermocouple locations, in relation to the heat exchanger, are illustrated in Figure 3.

RESULTS

Air flow rates were calculated by determing air velocities and duct sizes. These calculations can be found in Appendix I. From these calculation;

Intake Air Flow Rate $\approx$ 3200 L/S

Exhaust Air Flow Rate $\approx$ 2100 L/S

This air flow is unbalanced. The exhaust air flow rate is lower than the intake air flow rate due to leakage from the fourteen growth room loading doors. These large removable doors, even with proper gasketing, still leak some air to the service corridors.

Appendix II shows average daily temperatures at various points around the heat exchanger. It can be seen that in the heating mode the incoming air was warmed from 3C° to 9C° above ambient temperatures. During the summer months, the heat exchanger assisted in cooling the incoming air by 2C° to 3C°. This slight cooling although not great, does assist in reducing the mechanical cooling requirement.

ECONOMIC ANALYSIS

In 1980 the cooperator collected energy data for a study on energy consumption in the mushroom industry. At that time, records; of energy use, fuel use, energy costs, and production were kept. During 1986 the cooperator again kept the same records to determine the cost savings by using the heat exchanger. These records indicate the total energy inputs to this system which includes:

- picking up raw material for compost
- making compost
- production of mushrooms
- harvest of mushrooms

The physical plant, equipment, and annual production were nearly identical from 1980 to 1986. The only major difference was the addition of the heat exchanger in 1985.

To compare costs of production from 1980 to 1986, fuel quantities for 1980 and 1986 will be used and multiplied by unit fuel costs for 1986. In this way costs rather than quantities will be compared.

TABLE #1 MEAN TEMPERATURE °C

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1980	-4.9	-7.4	-1.3	6.7	14.1	15.8	20.9	22.1	16.0	7.4	2.6	-5.1
1986	-5.3	-6.3	0.9	8.0	14.8	17.3	20.9	18.4	15.2	9.2	1.3	-1.8

Source: Delhi Research Station

TABLE #2

ENERGY USE & COST PER 1000 POUNDS (450Kg) OF MUSHROOMS PRODUCED

	QUANT. USED '80	QUANT. USED '86	1986 UNIT PRICES	1980 QUANT. x '86 PRICES	1986 QUANT. x '86 PRICES
FURNACE OIL	145L	91	$ 0.31	$ 44.95	$ 28.21
PROPANE	13L	75	$ 0.22	$ 2.86	$ 16.50
ELECTRICITY	679kWh	774	$ 0.04	$ 27.16	$ 30.96
GASOLINE	38L	25	$ 0.44	$ 16.72	$ 11.00
DIESEL FUEL	4L	5	$ 0.38	$ 1.52	$ 1.90
			TOTAL	$ 93.21	TOTAL $ 88.57

Energy costs for 1980 - no heat exchanger = $93.21/1000 pounds mushrooms

Energy costs for 1986 - with heat exchanger = $88.57/1000 pounds mushrooms

Actual 1986 production was 803,000 pounds

∴ Annual cost savings due to heat exchanger

$$= \frac{\$\ 4.64}{1000\ \text{lb.}} \times 803{,}000\ \text{lb.}$$

$$= \$3{,}725.92$$

∴ Annual cost savings is approximately $3700

HEAT EXCHANGER CONSTRUCTION COSTS:

Engineering design and supervision	$ 1,635
Coroplast sheets & silicone sealant	3,047
Roll filters	245
Sheet metal and fabrication	1,620
Angle iron, weather stripping, etc.	860
TOTAL COST	$ 7,407

$$\text{Simple payback} = \frac{\text{Capital cost}}{\text{Savings per year}}$$

$$= \frac{\$7{,}407}{\$3{,}700/\text{YR}}$$

$$\approx 2\ \text{Years}$$

∴ From this analysis it appears that the heat exchanger recovers enough energy in 2 years to offset the inital cost of the unit.

CONCLUSIONS:

1.) This farm built heat exchanger works well recovering heat from the exhaust ventilation air.

2.) Cost savings for this heat exchanger are approximately $3,700 per year.

3.) With an initial capital cost of approximately $7,400 this heat exchanger has a payback of roughly 2 years.

4.) The heat exchanger also provides a benefit during summer operation by cooling the incoming air by 2 - 3C°.

SUMMARY

From this testing, it would appear that air-to-air heat exchangers are ideally suited to mushroom production facilities. During the heating period, heat is recovered from the plant exhaust air, while in the summer the incoming ventilation air is cooled with the heat exchanger. Where major changes are necessary to incorporate a heat exchanger, the economics may be considerably different.

ACKNOWLEDGEMENTS

This on-farm demonstration of a farm-built heat exchanger proved to be very successful in providing useful data. The author wishes to acknowledge his appreciation to the cooperator, Mr. Tony Hermans and his staff for their genuine interest in this heat exchanger demonstration. Without their time and effort in recording data, this report would not be possible. As well, thanks to Mr. Harry Cartmell for his helpful ideas in regards to this project.

This demonstration was made possible by partial funding by the Agricultural Energy Centre of the Ontario Ministry of Agriculture and Food, and the Ontario Ministry of Energy.

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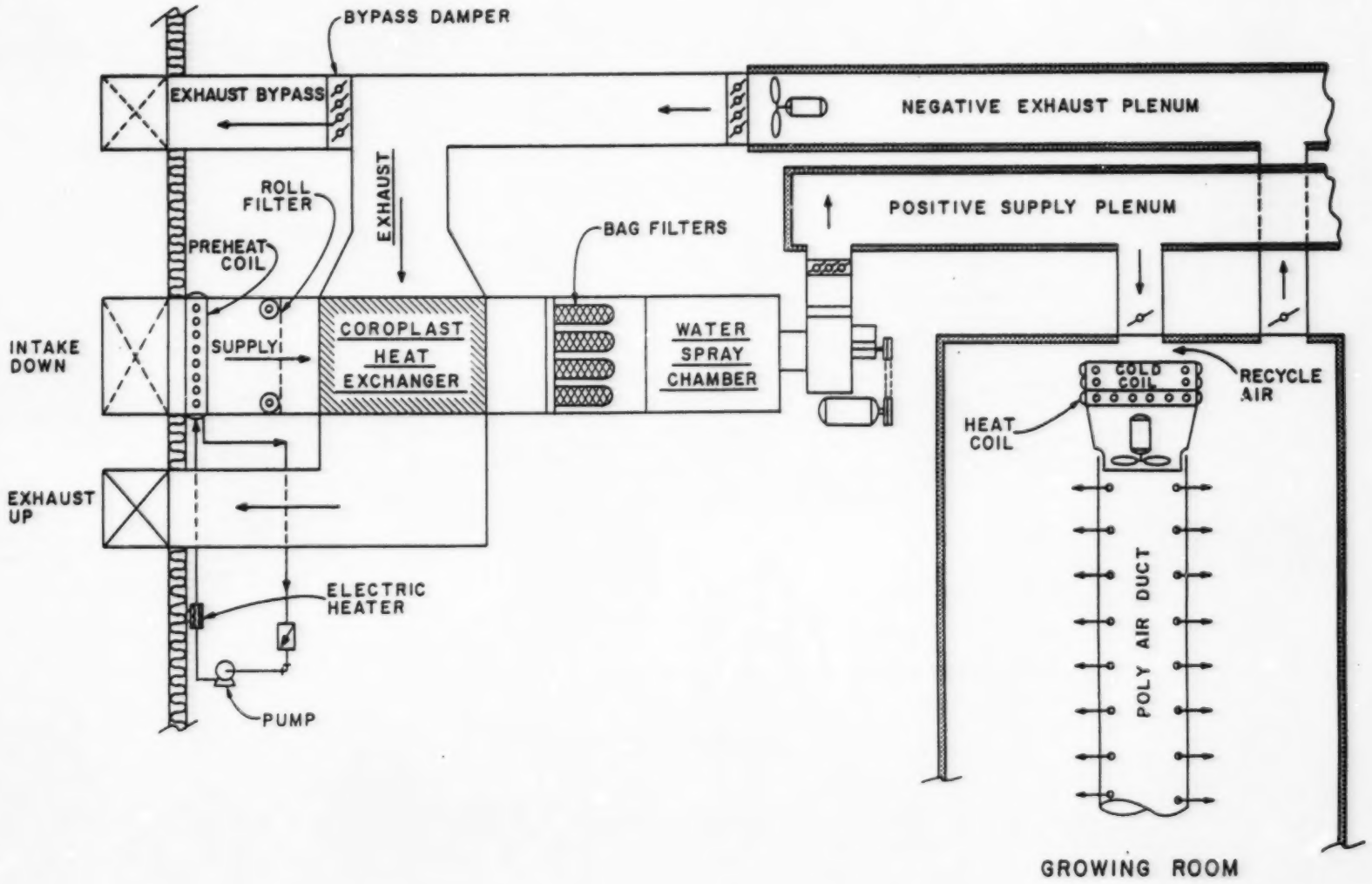


FIGURE 1 : AIR SUPPLY & EXHAUST SYSTEMS

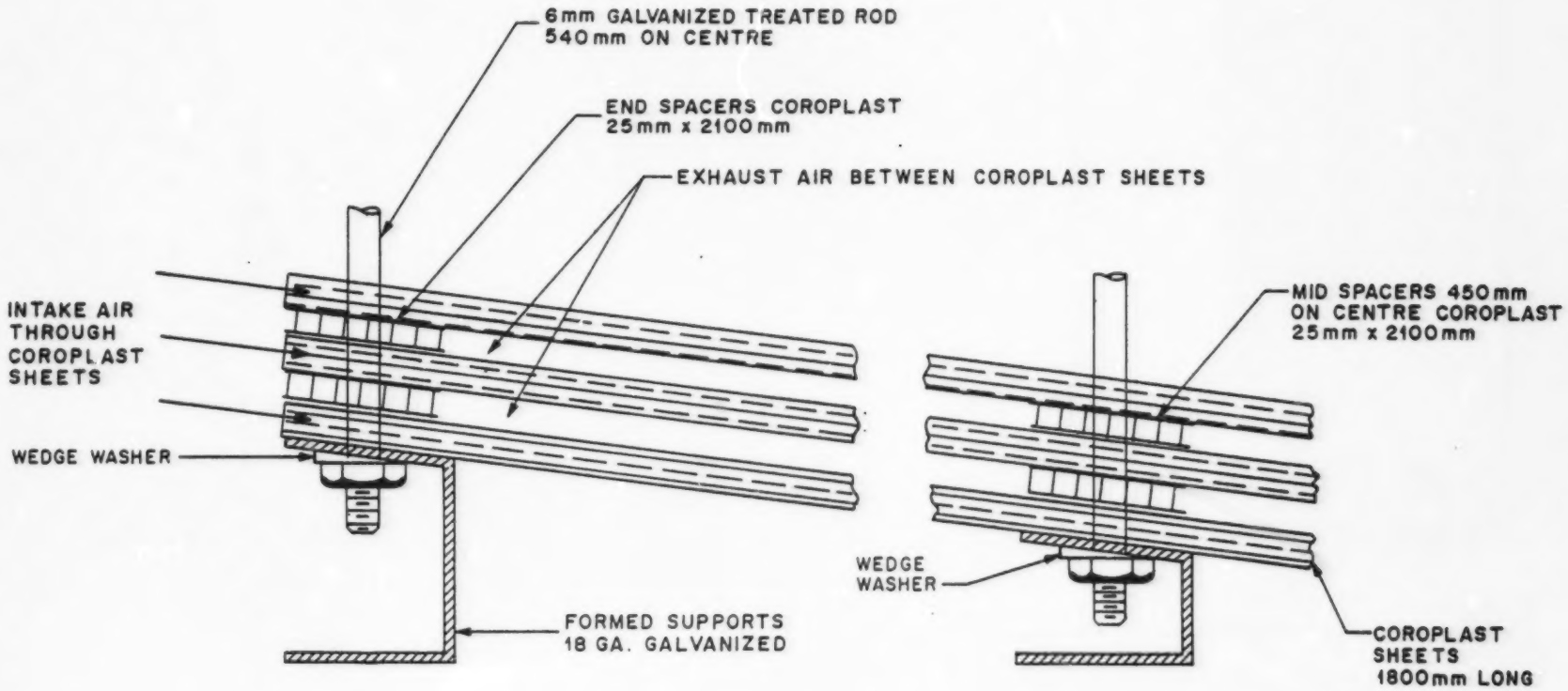
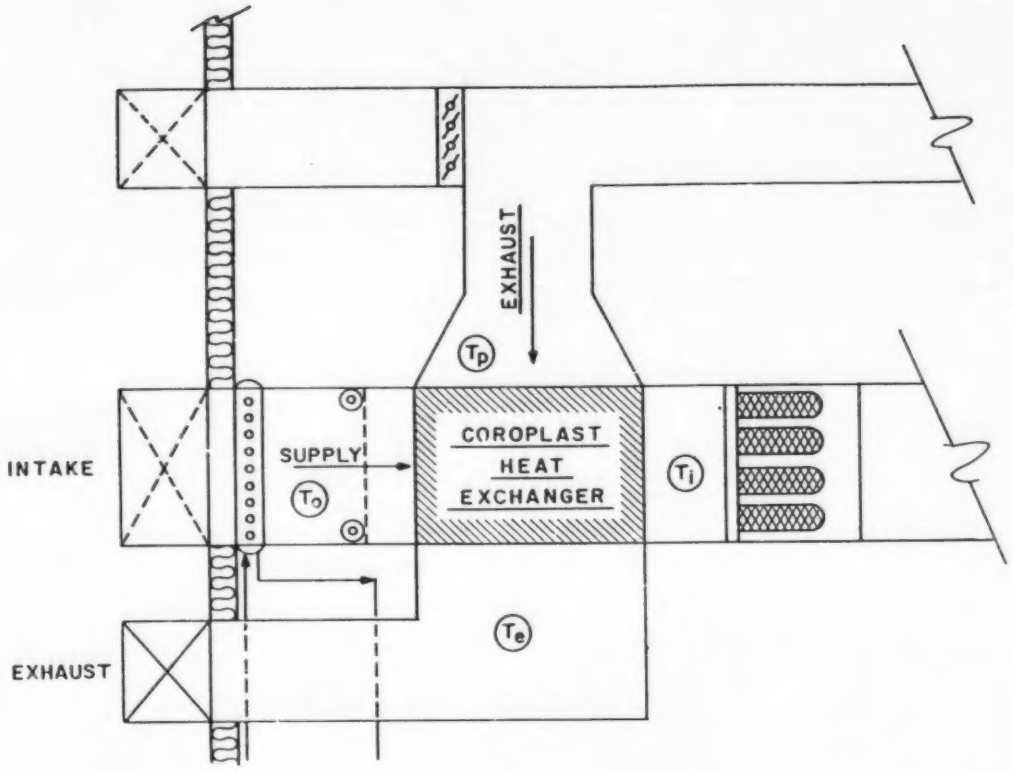


FIGURE 2 : SIDE CROSS-SECTION OF COROPLAST HEAT EXCHANGER MATRIX



LEGEND:

T_o = TEMPERATURE OF OUTSIDE AIR BEFORE HEAT EXCHANGE

T_I = TEMPERATURE OF OUTSIDE AIR AFTER HEAT EXCHANGE

T_p = TEMPERATURE OF EXHAUST AIR BEFORE HEAT EXCHANGE

T_e = TEMPERATURE OF EXHAUST AIR AFTER HEAT EXCHANGE

FIGURE 3: THERMO COUPLE LOCATIONS

APPENDIX I INTAKE AND EXHAUST AIR FLOW RATES

Air velocities were taken, with the heat exchanger in place, by means of an Alnor Velometer. The air velocity was done on a fifteen point grid inside the duct.

INTAKE AIR VELOCITY PROFILE

2030 mm

1.5	1.5	1.3	1.4	1.5
1.5	1.3	1.3	1.4	1.5
1.5	1.2	1.2	1.0	1.5

1140 mm

Average air velocity = 1.37 m/S

$\therefore Q = AV$

$= 1.14\ m \times 2.03\ m \times 1.37\ m/S \times 1000\ L/m^3$

$= 3107.5$

$\approx 3200\ L/S$

$\therefore$ Intake air supply is approximately 3200 L/S

EXHAUST AIR VELOCITY PROFILE

1750 mm

1.3	1.3	1.4	1.0	0.5
1.0	1.3	1.5	1.2	0.5
1.0	1.1	1.2	1.2	0.4

1140 mm

Average air velocity = 1.06 m/S

$\therefore Q = 1.14\ m \times 1.75\ m \times 1.06\ m/S \times 1000\ L/m^3$

$= 2114.7$

$\approx 2100\ L/S$

$\therefore$ Exhaust air discharge is approximately 2100 L/S

APPENDIX II AVERAGE DAILY TEMPERATURE READINGS AND HEAT RECLAIMED OR HEAT REMOVED FROM AMBIENT VENTILATION AIR

TEST DATE	AVERAGE DAILY TEMP. READINGS (°C)				AVERAGE R.H.	Δ ENTHALPY kJ/kg DRY AIR	HEAT RECLAIMED PER HOUR
	To	Ti	Tp	Tc			
Jan. 28	-8	-3	11	4	67	4.5	64.8MJ/h
Feb. 5	0	8	16	4	84	8.0	115.2MJ/h
Mar. 15	1	10	18	6	72	8.0	115.2MJ/h
Apr. 28	10	15	17	15	74	5.5	79.2MJ/h
May 02	11	15	16	15	39	4.0	57.6MJ/h
Sept.26	9	12	15	12	84	3.0	43.2MJ/h
Oct. 02	4	11	15	6	66	8.0	115.2MJ/h
Nov. 02	2	10	16	4	97	9.0	129.6MJ/h
Nov. 24	0	7	15	2	77	7.0	100.8MJ/h
Dec. 03	-3	0	15	6	86	3.5	50.4MJ/h

							HEAT REMOVED FROM INCOMING AIR PER HOUR
May 14	23	21	19	24	63	2.0	28.8 MJ/h
July 06	31	28	26	31	65	3.0	43.2 MJ/h
July 25	27	24	21	27	85	3.0	43.2 MJ/h
Sept 03	23	21	19	23	81	2.0	28.8 MJ/h
Sept 07	27	24	23	27	83	3.5	50.4 MJ/h

HEATING VALUES OF CONVENTIONAL FUELS

NATURAL GAS	37.7 MJ/m^3
PROPANE	25.5 MJ/L
#2 FUEL OIL	38.7 MJ/L
ELECTRICITY	3.6 MJ/kWh